DIFFERENTIAL PHASE MODULATED MULTI-BAND ULTRA-WIDEBAND COMMUNICATION SYSTEM

The present invention relates to an ultra wideband (UWB) communication system for wireless personal area networks (WPANs). More particularly, the present invention relates to a differential phase modulated multi-band UWB communication system for WPANs and its associated demodulation system.

Most of the implementations and research concerning UWB communication systems has been directed to low data rate applications. Such low data rate UWB systems are typically designed with low pulse repetition rates. As a result, the pulse amplitude and inter-pulse distance can be made high. This results in a well known benefit of UWB, namely, resilience to interference, such as multipath interference.

However, a UWB signal, as defined by the Federal Communications Commission (FCC), either has more than a 20% fractional bandwidth or occupies more than 500MHz of spectrum, which means that a UWB signal doesn't need to be a very short impulse occupying the whole spectrum at the same time. A UWB signal can use multiple bands to encode information in parallel so that information is independent encoded in the different bands. This encoding process results in very high bit rate systems realized with relatively low signaling rates.

All systems are bound by channel capacity

$$C = B\log_2(1+S/N)$$

where

C = maximum channel capacity (bits/sec)

B = channel bandwidth (Hz)

S = signal power (watts)

N = noise power (watts)

such that the upper bound on the capacity of a channel grows linearly with total available bandwidth B. Therefore, UWB systems, occupying 2GHz or more, have greater room for expansion than systems that are more constrained by bandwidth and have great potential for support of future high-capacity wireless systems.

New applications of UWB technology, such as multimedia video distribution networks, require a high data rate system, e.g., 100Mbps to 500Mbps. One study compared IEEE 802.11b, Bluetooth, IEEE 80211a and UWB found that UWB spatial capacity exceeded all others by several orders of magnitude,

see FIG. 1. However, conventional UWB techniques for achieving such a high data rate system are likely to require high pulse repetition rates, reducing the distance between successive pulses. This reduction results in conventional UWB systems that are prone to multipath interference.

In addition to supporting higher data rates, future UWB systems also need to be low cost if they are to complete favorably with narrow band systems. Given, that UWB receivers must be low cost, modulation techniques become the focus of study. The use of modulation techniques that require coherent receivers does not lead to low-cost implementations. The main reason for this is that coherent receivers require sophisticated circuitry (logic) in order to be able to generate local reference signals that are coherent in phase/frequency to the received waveform. In addition, the performance of such coherent receivers suffers from multipath/channel noise-induced phase mismatch.

A frequent design objective is that UWB modulation systems be demodulated with non-coherent receivers. Even though the theoretical performance of such no-coherent receivers is lower than that of their coherent counterparts, the performance of the practical implementations of the two receivers may be identical. In fact, in cases of heavy multipath interference, the con-coherent receivers may perform even better than their coherent counterparts without requiring additional phase/frequency or multipath mitigation circuits.

This use of WEB spectrum is not based on the traditional impulse radios, but on using multiple bands and has several other tangible benefits than those already discussed, including:

- increased scalability and adaptability over single band designs;
- better coexistence characteristics with systems such ad 802.11a; and
- leverages more tradition radio design techniques thereby reducing implementation risk.

Further, the complexity and power consumption levels of single band designs can be maintained and while also achieving these advantages.

The present invention provides a phase modulated UWB signal, conveying method and receiver and in a preferred embodiment is directed to a multi-band UWB signal where each band spans about 500MHz to 1 GHz. Within each such band, a flexible modulation scheme of the present invention is employed that comprises two-pulse duplets having a difference set to Π/2 or 90E. This modulation scheme allows adaptation of the data rate to the sub-band channel conditions. Within each band, time, amplitude and phase modulations are employed. In addition, a pseudorandom frequency sequence is employed to provide sufficient reduction of multi-user interference.

FIG. 1 illustrates a spatial capacity comparison between IEEE 802.11, Bluetooth, and UWB.

FIG. 2 is a typical signal waveform for Π/2 differential phase UWB modulation.

FIG. 3 is a non-coherent (differentially coherent) receiver to demodulate a Π/2 differential phase modulated multi-band UWB signal according to the present invention.

FIG. 4 is a typical emitted multi-band waveform in which each pulse pair has the same frequency.

FIG. 5 is a demodulated waveform illustrating pulse trains with 1-bit per pulse in which combinations with PPM, according to the present invention, will produce more bits per pulse.

It is to be understood by persons of ordinary skill in the art that the following descriptions are provided for purposes of illustration and not for limitation. An artisan understands that there are many variations that lie within the spirit of the invention and the scope of the appended claims. Unnecessary detail of known functions and operations may be omitted from the current description so as not to obscure the present invention.

In a preferred embodiment, the present invention provides a system and method for an ultra wideband communication system having multiple bands, i.e., a multi-band ultra-wideband communication system. Each of the bands spans 500MHz to 1GHz, approximately. A flexible modulation scheme is provided by the method of the present invention within each band.

For high-speed UWB applications, the modulation scheme of the present invention takes the form of duplets of pulses, i.e., pairs of pulses, for each bit transmitted. The phase difference between the first part of the pulse and the second part of the pulse is set to Π/2 or 90°. FIG. 2 illustrates the modulation scheme of the present invention wherein in order to transmit a bit value of 1, for example when $d_n=1$, a cos(wt) signal 201 is transmitted during a first sub-pulse time slot and then a sin(wt) signal 202 is transmitted during a second sub-pulse time slot. Transmission of bit 0 when $d_n=0$ takes the form of transmission of sin(wt) during a first sub-pulse time slot followed by transmission of cos(wt) in a second sub-pulse time slot. This modulation scheme allows adaptation of the data rate to the sub-band channel conditions.

In a preferred embodiment, the modulation scheme of the present invention is combined with at least one of pulse position modulation and multi-band modulation. In the case of combination with a multi-band modulation scheme, the frequency of each pulse-duplet of a succession of pulse-duplets is different from that of the preceding or the following pulse-duplets of the succession. Such a multi-band transmission of pulses creates multiple bands of which each band utilizes Π/2 modulation in combination with other modulation schemes. A primary advantage of this modulation scheme is simplicity of a non-coherent receiver implementation.

FIG. 3 illustrates a non-coherent demodulator according to a preferred embodiment of the present invention. This receiver is insensitive to phase and frequency mismatch between the received UWB

waveform and the locally generated waveform. As a result, the locally generated waveforms (from the VCOs 305) can just be free-running. As a result, implementation is simplified.

In a preferred embodiment, the receiver illustrated in FIG. 3 is suitable for demodulation of a multi-band signal. In such a system the expected center frequency of the received waveform has to be known in advance. The frequency sequence of the received waveforms can be established during transmission of a preamble or via transmission of a known reference sequence for a short period of time. Once the frequency of the received waveform is known, the corresponding frequency from the local oscillators (e.g., VCOs 305) is fed to the first multiplier (mixer). This process down-converts the incoming signal into a signal that is centered at DC, provided that the local frequency is approximately equal to that of the received signal. After the first mixing, the subsequence processing and circuit elements are identical for all frequencies.

FIG. 4 illustrates a typical emitted waveform 400(wherein each duplet has the same frequency) that is received by the receiver of FIG. 3 and then passed through a wideband band-pass filter (BPF) 301, followed with a low-noise amplifier (LNA) 302. The output of the LNA 302 is amplified/reduced to an appropriate level by the gain unit 303. The resulting signal is fed to the mixer 304. The mixer 304 multiplies the received waveform with the corresponding locally generated free-running sinusoidal waveform produced by the bank of Voltage Controlled Oscillators (VCOs) 305. The resulting mixed waveform is passed through a low-pass filter.

Further processing of this low-pass signal produces a single pulse for each bit transmitted via the phase of the signal. Additional bits per pulse can be transmitted by using pulse position modulation (PPM). FIG. 5 illustrates this further processed train of pulses. The demodulator converts the receiver's two-pulse duplets into a single pulse that is independent of frequency and phase mismatches. The sign 310 of the processed pulses corresponds to the transmitted data. Further integration 311 and sampling produces the required bits.

In alternative preferred embodiments, in order to further mitigate multipath and other interference, this topology can be combined with one or more other receiver techniques, such as, a RAKE receiver and equalization.

The receiver and method of the present invention can be used for wireless personal area networks, for conveying video, audio, text, pictures, and data for controlling sensors, alarms, computers, audio-visual equipment, and entertainment systems. For example, the contents of a digital camera can be downloaded to a computer wirelessly.

While the preferred embodiments of the present invention have been illustrated and described, it will be understood by those skilled in the art that various changes and modifications may be made, and

equivalents may be substituted for elements thereof without departing from the true scope of the present invention. In addition, many modifications may be made to adapt the teaching of the present invention to a particular situation without departing from its central scope. Therefore it is intended that the present invention not be limited to the particular embodiments disclosed as the best mode contemplated for carrying out the present invention, but that the present invention include all embodiments falling within the scope of the appended claims.